

VASCULAR-ACCESS SIMULATION SYSTEM  
WITH ERGONOMIC FEATURES

**Statement of Related Cases**

[0001] This case is related to U.S. Patent Applications S.N. \_\_\_\_\_ (Atty. Dkt. No. 115-001), S.N. \_\_\_\_\_ (Atty. Dkt. No. 115-002), S.N. \_\_\_\_\_ (Atty. Dkt. No. 115-003), and S.N. \_\_\_\_\_ (Atty. Dkt. No. 115-005), all of which are incorporated by reference herein.

**Field of the Invention**

[0002] The present invention relates generally to systems that simulate medical procedures for the purposes of training or accreditation. More particularly, the present invention relates to a system, apparatus and subsystems for simulating vascular-access procedures.

**Background of the Invention**

[0003] Medical practitioners, such as military medics, civilian emergency-medical personnel, nurses, and physicians, routinely perform vascular-access procedures (e.g., IV insertion, central venous-line placement, peripherally-inserted central catheter, etc). It is desirable for a practitioner to be proficient at performing these procedures since the proficient practitioner is far less likely to injure a patient and is almost certain to reduce the patient's level of discomfort.

[0004] Becoming proficient in vascular-access procedures requires practice. In fact, the certification and re-certification requirements of some states mandate a minimal number of needle sticks, etc., per year per provider. Historically, medical practitioners practiced needle-based procedures on live volunteers. More recently, simulation techniques and devices have been developed to provide training in vascular-access procedures without the use of live volunteers. U.S. Pat. No. 6,470,302 ("the '302 patent") surveys the art of medical-simulation devices and also discloses a vascular-access simulation system.

[0005] The vascular-access simulation system that is disclosed in the '302 patent includes an "interface" device and a computer system. To practice a vascular-access procedure, a user manipulates an "instrument," referred to in the patent as a "catheter unit assembly," which extends from the device and serves as a catheter-needle. Potentiometers and encoders within the interface device track the

motion and position of the instrument and relay this information to the computer system. The computer system performs a simulation of the surface and subsurface anatomy of human skin, and determines the effect of the instrument's motion on the skin's anatomy. Simulated results are displayed by the computer system. Using the motion information from the interface device, the computer system also generates a control signal that controls a force-feedback system that is coupled to the instrument. The force-feedback system generates various resistive or reactive forces that are intended to simulate the forces that are experienced by a medical practitioner during an actual vascular-access procedure. The user senses these forces during manipulation of the instrument.

[0006] The simulation system that is disclosed in the '302 patent has many shortcomings that substantially limit its utility as a training or accreditation tool. One shortcoming of that simulation system relates to ergonomics.

[0007] In particular, when manipulating the catheter-unit assembly of that system, a user's hands are in an awkward and unrealistic position (as compared to the position of the hands during an actual vascular access procedure). This is due, among other reasons, to the height of the interface device, which is a consequence of the layout and design of the mechanisms that compose the interface device.

[0008] Furthermore, the relative positioning and arrangement of mechanisms with which a user of that system interacts to practice a vascular access procedure is not ergonomic. Specifically, the simulation system enables a user to perform needle "insertion" as well as a "skin-stretch" technique. The skin stretch normally accompanies catheter insertion during an actual procedure to reduce a patient's level of discomfort and to anchor the vein that is being entered.

[0009] In the system that is disclosed in the '302 patent, the skin-stretch mechanism, which includes a belt —a mock skin—, resides within a casing that is attached to and separate from the housing in which the needle-insertion procedure is practiced. To simulate the skin-stretch technique, a user "stretches" the mock skin. In comparison with an actual procedure, the location at which a user stretches the mock skin is rather remote from the needle "insertion point." Furthermore, the surface of the mock skin is not co-planar with or at the same height as the needle insertion point. In an actual procedure, of course, they are (*i.e.*, the skin surface is the insertion point). This structural arrangement does nothing to promote a user's "suspension of disbelief" and does not provide a particularly realistic simulation.

**[0010]** The inability of prior-art vascular-access simulation systems to realistically simulate a vascular-access procedure limits their usefulness as a training or accreditation tool.

### **Summary**

**[0012]** The illustrative embodiment of the present invention is a simulation system that provides realistic training and practice for performing vascular-access procedures without using human subjects. Unlike some other prior-art simulation systems, the system is designed to provide ergonomically-correct hand position.

**[0013]** The illustrative embodiment of a vascular-access simulator includes a data-processing system and an interface device, referred to herein as a "haptics device." The haptics device provides the physical interface for performing vascular-access procedures. Some embodiments of the haptics device also provides mechanisms that enable a user to practice certain skin-interaction procedures (*i.e.*, palpation, occlusion and skin stretch).

**[0014]** In accordance with the illustrative embodiment, the various mechanisms within the haptics device are configured so that one or more of the following conditions are met:

- The profile of the haptics device remains relatively low — advantageously not substantially higher than a person's arm when it is resting flat on a surface.
- The shape of the haptics device is not overtly inconsistent with human anatomy (*e.g.*, an arm, *etc.*).
- When practicing a vascular-access procedure using the haptics device, the position of a user's hands is similar to the position of the hands when performing an actual vascular-access procedure.
- The sites at which the palpation and skin stretch techniques are performed are correct relative to one another (in terms of the sites of these techniques during an actual vascular-access procedure).
- The sites at which the occlusion and skin stretch techniques are performed are correct relative to one another (in terms of the sites of these techniques during an actual vascular-access procedure).

- The sites at which the occlusion and skin stretch techniques are performed are correct relative to the site at which the catheter/needle is inserted into the haptics device (in terms of the sites of these techniques during an actual vascular-access procedure).
- The various mechanisms of the haptics device are beneath the “skin” of the haptics device.

[0015] Simulators described herein therefore more closely simulate a real vascular-access procedure than simulators in the prior art. This more realistic simulation is expected to result in a more useful training experience.

### **Brief Description of the Drawings**

[0016] **FIG. 1** depicts vascular-access simulation system **100** in accordance with the illustrative embodiment of the present invention.

[0017] **FIG. 2** depicts functional elements of haptics device **102**, which is a part of vascular-access simulation system **100**.

[0018] **FIG. 3** depicts a perspective view of haptics device **102**.

[0019] **FIG. 4** depicts a perspective view of an illustrative embodiment of an arrangement of various functional modules of haptics device **102**.

[0020] **FIG. 5** depicts a top view of the arrangement of **FIG. 4**.

[0021] **FIG. 6** depicts pseudo skin **220** overlying the arrangement of functional modules of haptics device **102**.

[0022] **FIG. 7** depicts an exploded view of haptics device **102**.

[0023] **FIG. 8** depicts vascular-access simulation system **100** wherein haptics device **102** is positioned directly in front of monitor **108**.

### **Detailed Description**

[0024] The terms and phrases listed below are defined for use in this specification as follows:

[0025] “**End Effector**” means a device, tool or instrument for performing a task. The structure of an end effector depends on the intended task. For example, in the illustrative embodiment, the end effector is intended to be used to simulate a

vascular access procedure, and is therefore implemented as a catheter-needle module. Those skilled in the art will recognize that term “end effector” is borrowed from robotics, where it has a somewhat different definition: a device or tool connected to the end of a robot arm.

[0026] “**Imitation**” means an artificial likeness that is intended to be substantially similar to an item being imitated; a copy. For example, “imitation skin,” which is used in conjunction with the illustrative embodiment of the present invention, is intended to mimic or copy genuine skin via appropriate selection of color, appearance, feel, and overall presentation.

[0027] “**Mock**” means “representative;” a stand-in for a genuine article, but not intended to closely imitate the genuine article. A mock article will never be confused with the genuine article and typically does not promote a suspension of disbelief that the mock article is the genuine article. For example, “mock skin” is not intended to mimic genuine skin, and typically departs from it in terms of color, appearance, feel or overall presentation.

[0028] “**Pseudo**” is an inclusive term that means “imitation” or “mock.” For example, pseudo skin is meant to encompass both imitation skin and mock skin.

[0029] “**Skin**” means genuine skin.

[0030] Additional definitions are provided later in this Detailed Description.

[0031] This *Detailed Description* continues with an overview of a vascular-access simulator in accordance with the illustrative embodiment. Following the overview, specific embodiments of certain features of the simulator are described in greater detail.

#### *Overview*

[0032] The illustrative embodiment of the present invention pertains to a simulation system that provides realistic training and practice for vascular-access procedures without using human subjects. As depicted in FIG. 1, vascular-access simulator **100** includes haptics device **102** and data-processing system **104**.

[0033] Haptics device **102** provides the physical interface for performing any of several simulated vascular-access procedures (e.g., intravenous catheterization, central venous line placement, sternal intraosseous insertion, etc.).

[0034] The term “haptics” (as in “haptics device **102**”) relates to touch (*i.e.*, the sense of touch). A fundamental function of haptics device **102**, and indeed any haptics interface, is to create a means for communication between users (*i.e.*, humans) and machines. This “communication” is possible since humans are capable of “mechanically” interfacing with their surroundings due, at least in part, to a sense of touch. This “sense of touch” includes sensations of pressure, texture, puncture, thermal properties, softness, wetness, friction-induced phenomena, adhesions, *etc.* Furthermore, humans also experience vibro-tactile sensations, which include the perception of oscillating objects in contact with the skin and kinesthetic perceptions (*i.e.*, awareness of one’s body state, including position, velocity, and forces supplied by the muscles). As will become clear later in this *Detailed Description*, our ability to perceive a variety of these sensations is exploited by haptics device **102**.

[0035] To the extent that some embodiments of simulator **100** are intended for use as a practice and training tool, it is advantageous for haptics device **102** to simulate vascular-access procedures as realistically as possible and provide a quantitative measure of the user’s performance of the simulated procedure. To this end, haptics device **102** possesses one or more of the following attributes, in addition to any others:

- It possesses sufficient degrees-of-freedom to simulate the relatively free movement of a needle/catheter during an actual vascular-access procedure.
- It offers the opportunity to perform all steps of a vascular-access procedure, including, for example, needle insertion, skin interactions (*e.g.*, palpation, skin stretch, *etc.*), catheter threading, *etc.*
- It generates appropriate skin- and venous-puncture forces.
- It measures or otherwise quantifies the effects of user actions on simulated anatomy.
- It generates appropriate haptic feedback (*i.e.*, feel) during skin-interaction steps.
- It is configured to provide ergonomically-correct hand position during simulated vascular-access procedures.
- It is small enough so that it can be positioned in front of a computer monitor so that the haptics device and the monitor are inline with a user’s forward-looking field of view.

- It is at least subtly suggestive of human anatomy and does not present any substantial departures therefrom so as to support a user's ability to suspend disbelief during a simulated vascular-access procedure.

[0036] Data-processing system **104**, which includes processor **106**, monitor **108**, keyboard **110**, mouse **112**, and speakers **114**, supports the visual aspects of the simulation and other functions described below. Processor **106** is a general-purpose processor that is capable of receiving and processing signals from haptics device **102**, running software for the visual portion of the vascular-access simulation including an anatomy simulator, running calibration software for calibrating the various sensing elements used in haptics device **102**, and sending control signals to haptics device **102** to support closed-loop force feedback, among other capabilities. Processor **106** comprises memory, in which the software described above is stored. In the illustrative embodiment, processor **106** is a personal computer.

[0037] Monitor **108** displays a rendering that is generated by processor **106**, in conjunction with the above-referenced software. The rendering, which in some embodiments is three-dimensional, is of a region of the body (*e.g.*, isolated arm, thorax, neck, *etc.*) on which a simulated vascular-access procedure is being performed. The rendering advantageously depicts visual aspects such as, without limitation, the anatomical structures that underlie skin, local deformation of the skin in response to simulated contact, and tracking of a "virtual" instrument (*e.g.*, a needle, *etc.*) through anatomical structures that underlie the skin.

[0038] Haptics device **102** is now described in further detail. For pedagogical purposes, haptics device **102** is depicted in FIG. 2 as comprising several functional modules or elements. These include:

- End effector or Needle/catheter module **218**;
- Pseudo skin **220**;
- Palpation module **222**;
- Skin-stretch module **224**;
- Receiver or Needle-stick module **226**; and
- Electronics/communications interface **228**.

[0039] The functional elements of haptics device **102** listed above that relate to human anatomical features or are otherwise intended to generate resistive forces that would be sensed when penetrating such anatomical features (elements **222** –

**228**) are advantageously contained within housing **216** or otherwise located “underneath” pseudo skin **220**. In an actual vascular-access procedure, the needle or catheter, of course, remains outside of the body until inserted during the procedure. Likewise, in accordance with the illustrative embodiment, the end effector—needle/catheter module **218**—remains outside of housing **216** and pseudo skin **220** until a portion of it is inserted during a simulated vascular-access procedure.

[0040] Pseudo skin **220** is a membrane that is used in conjunction with the simulation of skin-interaction techniques, such as palpation, occlusion, and skin stretch techniques. Pseudo skin **220** is advantageously, but not necessarily, imitation skin (*i.e.*, skin-like in appearance). In embodiments in which pseudo skin **220** is imitation skin, it possesses any one of a number of natural flesh tones. In some embodiments, pseudo skin **220** is at least somewhat resilient to enable a user to perform skin-interaction techniques. In some embodiments, pseudo skin **220** comprises a thermoplastic elastomer such as Cawiton®, which is available from Wittenburg, B.V., Hoevelaken, Netherlands. The use of imitation skin, as opposed to mock skin, is desirable because it helps a user to “suspend disbelief,” which contributes to making simulator **100** more useful as a training tool.

[0041] As depicted in FIG. 3, pseudo skin **220** is accessed for insertion and skin-interaction techniques (*e.g.*, palpation, occlusion, skin stretch, *etc.*) through openings **330** and **332** in housing **216**. Opening **330** defines palpation/occlusion region **331** (*i.e.*, the site at which palpation and occlusion techniques are performed) and opening **332** defines skin-stretch region **333** (*i.e.*, the site at which the skin-stretch technique is performed) and includes insertion region **334** for the end effector (*e.g.*, needle/catheter module **218**).

[0042] The ability to perform skin-interaction techniques provides a more realistic simulation of vascular-access procedures. In some embodiments, this ability is provided in conjunction with palpation module **222** and skin-stretch module **224**. These modules, and illustrative embodiments thereof, are described in further detail applicant’s co-pending U.S. Patent Application S.N. \_\_\_\_\_ (Atty. Dkt. 115-001).

[0043] Pseudo skin **220** is disposed adjacent to the inside surface of housing **216** so that it appears to be nearly co-extensive (*i.e.*, co-planar) with housing **216** at openings **330** and **332**. This is intended to create a subtle suggestion that the

surface of housing **216** is "skin" at regions other than where pseudo-skin **220** is accessed for skin-interaction techniques. Consistent with human anatomy, the remaining functional elements of haptics device **102** (elements **222** – **228**), with the exception of needle/catheter module **218**, are "hidden" beneath pseudo skin **220**.

[0044] The end effector (e.g., needle/catheter module **218**, etc.) is inserted into haptics device **102** at insertion region **334** at opening **332**. During insertion, a user holds handle **336** as desired. In some embodiments, simulator **100** is capable of sensing orientation of the end effector, such as to determine the direction the bevel of a needle or catheter. This is an important aspect of the real insertion technique, since proper bevel orientation reduces a patient's discomfort during needle/catheter insertion. In some embodiments, needle/catheter module **218** is configured to be very similar to a real needle and catheter.

[0045] Once inserted into haptics device **102**, the tip of needle/catheter module **218** engages receiver **226**, which, for the illustrative embodiment of a vascular access simulator, is referred to as a "needle-stick module." Needle-stick module **226** supports the continued "insertion" of the needle/catheter module **218**. In particular, in some embodiments, needle-stick module **226** is configured to provide one linear degree of freedom and two rotational degrees of freedom (i.e., pitch and yaw). The linear degree of freedom provides a variable insertion depth, enabling a user to advance needle/catheter module **218** into the "patient's arm" or other body part (i.e., haptics device **102**). The rotational degrees of freedom enable a user to move (an engaged) needle/catheter module **218** up or down and left or right. In some embodiments, needle-stick module **226** measures insertion depth, and pitch (up/down) and yaw (left/right) angles.

[0046] In some embodiments, needle-stick module **226** provides "force feedback" to a user, whereby the user senses a variable resistance during continued advance (insertion) of needle-stick module **218**. The resistance is intended to simulate penetration of the skin, a vein, and harder structures such as ligaments, bones, and the like. The resistance advantageously varies with insertion depth and the pitch and yaw of needle/catheter module **218**, as described further below.

[0047] It will be understood that the "measurements" of angle, position, etc. that are obtained by the functional elements described above are obtained in conjunction with various sensors and data-processing system **104**. In particular, most of the functional elements described above include one or more sensors. The

sensors obtain readings from an associated functional element, wherein the readings are indicative of the rotation, displacement, *etc.*, of some portion of the functional element. These readings provide, therefore, information concerning the manipulation of needle/catheter module **218** in addition to any other parameters.

[0048] Each sensor generates a signal that is indicative of the reading, and transmits the signal to electronics/communications interface **228**. Sensors used in some embodiments include, without limitation, potentiometers, encoders, and MEMS devices. Those skilled in the art will know how to use and appropriately select sensors as a function of their intended use in conjunction with the functional elements described above.

[0049] Electronics/communications interface **228** receives the signals transmitted by the various functional elements of haptics device **102** and transmits them to data-processing system **104**. In some embodiments, as an alternative to transmitting the received signals, electronics/communications interface **228** generates new signal(s) based on the received signals, and transmits the new signals to data-processing system **104**. This latter approach requires a substantial increase in processing power and data management (relative to simply transmitting the received signals) and is generally a less-preferred approach. As described later below, electronics/communications interface **228** also receives signals from data processing system **104** and transmits them to needle-stick module **226** as part of a closed loop force-feedback system. Furthermore, electronics/communications interface **228** distributes power to the various functional modules, as required.

[0050] Data-processing system **104** receives the measurement data and, using the simulation software, calculates the forces that are being applied by the user during the skin-interaction procedures. Furthermore, using an anatomical model, data-processing system **104** calculates the position and angle of a virtual needle within a simulated anatomy (*e.g.*, arm, *etc.*). Data-processing system **104** displays, on monitor **108**, a rendering of the appropriate anatomy (*e.g.*, arm, *etc.*) and displays and tracks the course of a virtual needle within this anatomy.

[0051] Furthermore, based on the position and course of the virtual needle (as calculated based on the position and orientation of needle/catheter module **218**), data-processing system **104** generates control signals that are transmitted to needle-stick module **226**. These control signals vary the resistive force presented by needle-stick module **226** to account for various anatomical structures (*e.g.*, vein,

tissue, tendons, bone, *etc.*) that needle/catheter module **218** encounters, based on the simulation. As a consequence, the resistance to continued needle/catheter insertion that is experienced by a user of simulator **100** is consistent with the resistance that would be sensed by a practitioner during an actual vascular access procedure.

[0052] In the illustrative embodiment, the functional modules described above are realized as independent, stand-alone mechanisms. In some other embodiments, the functions represented by two or more of these functional modules are combined into an integrated mechanism.

[0053] Having completed the overview of vascular-access simulator **100** and haptics device **102**, the orientation of the various modules relative to one another and their position within housing **216** and relative to pseudo skin **220** will be described in further detail below.

[0054] It is the inventors' belief that, to the extent a user's interaction with haptics device **102** more closely tracks a practitioner's experience of performing the actual procedure (that the device is designed to simulate), the training experience is more useful. In this regard, the utility of a device such as haptics device **102** is enhanced by a design that is heavily influenced by form-function considerations and ergonomics. And, to that end, the illustrative embodiment of haptics device **102** has been strongly influenced by such considerations. In particular, and as described more fully below, considerations such as the positions of the functional modules (*e.g.*, modules **222**, **224**, **226**, *etc.*) relative to one another and relative to pseudo skin **220**, as well as the shape and dimensions of housing **216** have been taken into account in the design of haptics device **102**.

[0055] Referring now to FIG. 3, housing **216** is defined to have anterior end **338**, posterior end **340**, lower surface **342**, and upper surface **344**. Lower surface **342** typically is disposed on a working surface (*e.g.*, table, *etc.*). In the illustrative embodiment, user interactions with haptics device **102** occur near upper surface **344** of housing **216**. In some embodiments, housing **216** is subtly shaped like a portion of a human arm, yet is nondescript enough to avoid creating a discontinuity between what is seen and what is felt.

[0056] Pseudo skin **220** is accessible through openings **330** and **332** to perform simulated skin interaction techniques and needle/catheter insertion. In the illustrative embodiment, pseudo skin **220** is disposed adjacent to the inside surface

of housing **216** so that it appears to be nearly co-extensive (*i.e.*, co-planar) with housing **216** at openings **330** and **332**. This is intended to create a subtle suggestion that the surface of housing **216** is “skin” at regions other than where pseudo-skin **220** is accessed. Consistent with human anatomy, the remaining functional elements of haptics device **102** (elements **222** – **228**), with the exception of needle/catheter module **218**, are “hidden” beneath pseudo skin **220**. In some other embodiments, pseudo skin **220** is simply positioned across openings **330** and **332**, and in yet some additional embodiments, the pseudo skin is disposed above the openings.

[0057] Skin-stretch region **333**, which is accessible through opening **332**, is proximal to anterior end **338** of housing **216** (relative to palpation/occlusion region **331**). Palpation/occlusion region **331**, which is accessible through opening **330**, is proximal to posterior end **340** of housing **216** (relative to skin-stretch region **333**). Insertion region **334**, which is accessible through opening **330**, is flanked by skin-stretch region **333** toward the anterior end and palpation/occlusion region **331** toward the posterior end. The relative positions at which a user interacts with haptics device **102** to practice these techniques is consistent with their relative positions during an actual vascular-access procedure. That is, a practitioner, sitting in front of a patient, would stretch the patient’s skin and then insert the needle/catheter into the skin “behind” (from the practitioner’s perspective) the stretch site. Likewise, the occlusion procedure would normally occur “behind” the insertion point. The site at which a practitioner palpates a patient’s arm is typically coincident with the insertion point. In the illustrative embodiment of haptics device **102**, a user “palpates” pseudo skin **220** “behind” insertion region **334**.

[0058] FIG. 4 depicts a perspective view of an embodiment of some of the functional modules of haptics device **102** and their relative positions within housing **216**. Depicted in this Figure are skin-stretch module **224**, receiver or needle-stick module **226**, palpation module **222**, and electronics/communications interface **228**. FIG. 5 depicts a top view of these functional modules, FIG. 6 depicts pseudo skin **220** overlying the various functional modules, and FIG. 7 depicts an exploded view showing the various functional modules, pseudo skin **220** and upper and lower portions of housing **216**. FIG. 8 depicts haptics device **102** in use in conjunction with data processing system **104**.

[0059] Referring now to FIGs. 4 and 5, skin-stretch module **224**, receiver or needle-stick module **226**, palpation module **222**, and electronics/communications interface **228** are engaged to base **446**. The modules that are depicted in FIG. 4 would be oriented within housing **216** (not depicted in FIG. 4) such that skin-stretch module **224** is proximal to anterior end **338** of housing **216** and electronics/communications interface **228** is proximal to posterior end **340** of housing **216**. The electrical interconnections between electronics/communications interface **228** and the other functional modules, as described earlier in this specification, can be seen in FIGs. 4 and 5.

[0060] The relative position of specific functional modules within housing **216** is consistent with the sites at upper surface **344** at which a user accesses those functions. In particular, skin-stretch module **224** is proximal to anterior end **338** of the housing relative to palpation module **222** and relative to at least the portion of receiver module **226** that receives needle/catheter module **218**. Likewise, palpation module **222** is proximal to posterior end **340** of the housing relative to skin-stretch module **224** and relative to the portion of receiver module **226** that receives needle/catheter module **218**. The portion of receiver module **226** that receives needle/catheter module **218** is flanked by skin-stretch module **224** toward anterior end **338** and by palpation module **222** toward posterior end **340**.

[0061] In the illustrative embodiment, a portion of receiver module **226** is disposed in an open region between standoffs of palpation module **222**. If receiver module **226** were not disposed in this region, then either the length or the height of housing **216** would have to be increased. It is undesirable to increase the length because doing so would further separate the sites at upper surface **344** at which a user practices the various techniques. In particular, the palpation site would be rather remote from the needle insertion point. In an actual vascular-access procedure, these sites, of course, are virtually coincident. It is undesirable to increase the height of the housing because, if placed in front of a monitor on which the visual portion of the simulation is being displayed, the housing will obscure the view. Furthermore, the greater height can force the hands into an unrealistic position in terms of the procedure being practiced.

[0062] This design constraint biased the design of palpation module **222** toward one in which standoffs are used to elevate the palpation module to recover

space that might otherwise be lost. And this prompted the use of two actuating devices, rather than one, as could have otherwise been used.

[0063] Electronics/communications interface **228** is vertically oriented such that its major surface is oriented orthogonal to the uppermost surface of palpation module **222**. It is advantageous to orient interface **228** in this manner since it reduces the length of housing **216** (as compared to orienting the interface with its major surface parallel to the uppermost surface of palpation module **222**). And orienting interface **228** in this manner does not affect the height of housing **216** since, in this orientation, the interface is no higher than the uppermost surface of palpation module **222**.

[0064] Arranging the functional modules as described above; that is, in a generally horizontal arrangement rather than in a vertical arrangement, enables the use of a relatively low-profile housing for haptics unit **102**. This is desirable because it facilitates positioning housing **216** in front of a computer display without obscuring any portion of the screen, as is depicted in FIG. 8.

[0065] FIG. 8 depicts simulator **100**, which comprises data processing system **104** (including processor **106**, monitor **108**, keyboard **110**, mouse **112**) and haptics device **102** (including housing **216** and the internal functional modules and end effector **218**). As depicted in FIG. 8, haptics device **102** and monitor **108** are inline with a user's forward-looking field of view. This is desirable since a user looks to the monitor to view the visual portion of the simulation. (See, e.g., applicant's co-pending U.S. Patent Application S.N. \_\_\_\_\_ (Atty. Dkt. 115-005). To the extent that the user interfaces with haptics device **102** at a location that is not directly in front of monitor **108**, there is an inconsistency that does not promote a "suspension of disbelief" on the part of the user. To ensure that haptics device **102** does not obscure any portion of the screen, the functional modules are dimensioned and arranged so that the top of housing **216** advantageously has a height that is no more than about 5 inches, and more preferably has a height of about 4 inches or less.

[0066] As previously described, the various functional modules of haptics device **102**, with the exception of needle/catheter module **218**, are disposed beneath pseudo skin **220**. This is, of course, consistent with the experience of performing a vascular access procedure. That is, the interactions occur at the skin. In the illustrative embodiment, the end effector (e.g., needle/catheter module **218**,

*etc.*) is inserted at insertion region **334** through opening **648** in pseudo skin **220**. Furthermore, arranging the functional modules as described above, and beneath pseudo skin **220**, results in the correct hand position for a user of haptics device **102**, with reference to an actual vascular-access procedure.

[0067] FIG. 7 depicts an exploded view of haptics device **102** showing the relative positioning of the various functional modules within housing **216**. In particular, FIG. 7 depicts lower portion **750** of housing **216**, base **446**, skin-stretch module **224**, receiver module **226**, palpation module **222**, electronics/communications interface **228**, pseudo skin **220**, and upper portion **752** of housing **216**.

[0068] It is to be understood that the above-described embodiments are merely illustrative of the present invention and that many variations of the above-described embodiments can be devised by those skilled in the art without departing from the scope of the invention. For example, in this specification, numerous specific details are provided in order provide a thorough description and understanding of the illustrative embodiments of the present invention. Those skilled in the art will recognize, however, that the invention can be practiced without one or more of those details, or with other methods, materials, components, *etc.*

[0069] Furthermore, in some instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the illustrative embodiments. It is understood that the various embodiments shown in the Figures are illustrative, and are not necessarily drawn to scale. Furthermore, the particular features, structures, materials, or characteristics can be combined in any suitable manner in one or more embodiments. It is therefore intended that such variations be included within the scope of the following claims and their equivalents.